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# A Gait Rehabilitation pilot study using tactile cueing following Hemiparetic Stroke

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## ABSTRACT

Recovery of walking function is a major goal of post-stroke rehabilitation. Audio metronomic cueing has been shown to improve gait, but can be impractical and inconvenient to use in a community setting, for example outdoors where awareness of traffic is needed, as well as being unsuitable in environments with high background noise, or for those with a hearing impairment. Silent lightweight portable tactile cueing, if similarly successful, has the potential to take the benefits out of the lab and into everyday life. The Haptic Bracelets, designed and built at the Open University originally for musical purposes, are self-contained lightweight wireless devices containing a computer, Wi-Fi chip, accelerometers and low-latency vibrotactiles with a wide dynamic range. In this paper we outline gait rehabilitation problems and existing solutions, and present an early pilot in which the Haptic Bracelets were applied to post-stroke gait rehabilitation.

## Categories and Subject Descriptors

K.4.2 Social Issues: Assistive technologies for persons with disabilities, H.5.2 User Interfaces: Haptic I/O.

## General Terms

Human Factors.

## Keywords

Haptic Bracelets, stroke, gait rehabilitation, tactile metronome, haptic metronome, Parkinson's, fall prevention, walking, hemiparetic.

## 1. INTRODUCTION

The Haptic Bracelets are tactile communication and co-ordination devices, originally designed and built at the Open University for musical purposes, such as learning and teaching multi-limbed rhythms. In this paper we consider an early pilot study in which the Haptic Bracelets were applied to gait rehabilitation following a hemiparetic stroke.

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## 2. GAIT REHABILITATION FOLLOWING STROKE

### 2.1 Characteristics of post-stroke gait

As Belda-Lois et al [1] discuss, impairment of gait can have a major impact on a patient's life, and can impose substantial costs on health and social services [2]. Although the majority of stroke patients eventually recover an independent gait, many never regain a level of walking that allows common daily activities [3]. Thus, improvement of gait is a major goal of post stroke rehabilitation. Walking after a hemiparetic stroke is characterized by decreased speed [4], increased variability [5], and spatial and/or temporal asymmetry [6].



Figure 1. A full set of Haptic Bracelets

As a result, the non-paretic limb is regularly exposed to higher vertical forces [7]. Over time, this can lead to further problems, such as joint pain [8] and degeneration [9]. It may also contribute to the loss of bone mineral density in the paretic leg [10]. Individuals after stroke face double the risk of hip fracture after a fall for their age [11] with 80% of the fractures occurring on the side of the paretic leg [12]. An asymmetrical gait is associated with worse performance on clinical balance tests [13] and therefore may be linked to the increased risk of falling observed after stroke. Understanding and rehabilitating these features of hemiparetic gait is of vital importance, since walking affords a high level of independence, and thus a better quality of life for stroke survivors in general [14].

## 2.2 Existing gait rehabilitation approaches

Hollands et al [15] presented a systematic review of gait rehabilitation techniques after stroke, and identified external rhythmic cueing as a technique showing great promise for walking rehabilitation. Immediate effects of an auditory metronome have been reported, with chronic stroke patients able to synchronise to a metronome during treadmill walking [16]. Improvements in spatial [17] and temporal symmetry [18] and step time variability [19] were observed with auditory pacing, as was the ability to make gait adjustments in response to changes in the cue [20]. Auditory cueing has also been used in gait rehabilitation programmes, with significantly greater improvements in walking speed and stride length with auditory cueing compared to conventional gait training [21] and Bobath training [22].

Other modalities appear to have considerable promise for external cueing. Therapists routinely use touch to help stabilise patients and reduce postural sway. Visual spatial cues in the form of projected stepping-stones have also been used, and perturbation of the spatial phase of these cues shows promise [23]. However, these approaches can be intrusive, or can require laboratory installations, or both, whereas touch can be covert and more practical to apply in everyday life. It is known [24] that tactile cues can lead to an increase in stride length, without disrupting the natural gait rhythm in healthy participants.

## 3. THE HAPTIC BRACELETS

The Haptic Bracelets, designed and built at the Open University, are self-contained lightweight for wrists and ankles [25]. Each bracelet contains a computer, Wi-Fi chip, accelerometers and strong, crisp, low-latency vibrotactiles with a wide dynamic range. The bracelets were originally designed for musical purposes, to be worn in sets of four (each wrist and each ankle) – though, as in the present case, wearing fewer can have many useful applications. Multiple bracelets or sets can be coordinated and communicate together either natively or via laptop or smart phone. (The use of multiple sets is relevant to one of the therapeutic applications we describe below.) The vibrotactiles are very low latency, and can be felt in 6 milliseconds, helping greatly with timing issues in some uses, including one discussed below. The wireless Haptic Bracelets evolved out of the earlier Haptic Drum Kit [26] and our investigations of haptic technologies [27].



Figure 2. A single Haptic Bracelet

## 3.1 Modes of use of the Haptic Bracelets in gait rehabilitation

We propose three modes of use for using tactile cueing in gait rehabilitation. The first mode simply provides a portable tactile metronome. As previously noted, if tactile cueing demonstrates similar benefits to an auditory cue, this approach could have the benefit of being usable in a community setting, for example in the

street, while avoiding the inconvenience and dangers associated with wearing earphones when awareness of motor vehicles, bicycles and other pedestrians is needed. The bracelets could at the same time collect gait data via the in-built accelerometers for live streaming via Wi-Fi, or for storage and later analysis. When used as a tactile metronome, we anticipated that two communicating bracelets would be worn, one on each leg. The second approach is flexible interactive pacing, with the aid of a carer, therapist or partner. In situations where stumbles, environmental obstacles, changing slopes or other irregularities might make it impractical for the participant to keep in phase with a fixed beat, a partner wearing a communicating pair of bracelets could flexibly beat an appropriate pulse with arms or feet. The third approach is autonomous gait monitoring/reminding. In this mode, aimed at post-care, a pair of bracelets worn on the ankles could continually monitor gait asymmetry when the participant was walking, and could give gentle tactile metronomic guidance – for example when asymmetry exceeded a given limit. Note that at present, only the first two applications have been implemented.

## 3.2 Preliminary views of practitioners

As part of the system design process, before conducting a pilot test with a stroke survivor, we carried out two different participative demonstrations of the bracelets with two distinct meetings of physiotherapists with interests in neurology. Firstly, a brief invited talk, and participative demo, of the Haptic Bracelets was presented to a meeting of some fifty members of ACPIN, the professional Association of Chartered Physiotherapists with Interests in Neurology. This group (<http://www.acpin.net/>) has special interests in the neuro-rehabilitation of conditions such as Stroke, Parkinson's disease, Ataxia and Head injury. Three potential applications of the Haptic Bracelets in rehabilitation were outlined: the tactile metronome, flexible therapist-driven tactile cueing, and post-care live gait monitoring and feedback. The first two of these applications were demonstrated. In order to inform design work, as well as collecting detailed comments, survey feedback from some fifty ACPIN participants to three questions was evaluated to find out initial general views on the likely relative value of the three approaches.

**Table 1. General views of meeting of Physiotherapists with Interests in Neurology**

Proposition	Agree (or Agree Strongly)	Agree Strongly
The tactile metronome has the potential to influence practice	89%	55%
Live monitoring and feedback on gait symmetry has the potential to influence practice	83%	50%
Flexible tactile cueing has the potential to influence practice	93%	27%

Comments from members included:

*“Great for Parkinson's' Disease - Cueing to enable stepping - PD patients tend to “freeze” and use visual/audio cueing to trigger stepping - tactile cueing could assist this.”*

*“Stroke patients tend to have unequal stride length - the use of a metronome to encourage equal stepping by patients.”*

*“Use of feedback would assist therapists analysing gait + for patients to see their gait pattern.”*

Secondly, a presentation and participatory workshop was run for some seventeen physiotherapists from the Wye Valley NHS Trust. The workshop was part of a research day organised by a research facilitator from the West Midlands Stroke Research Network ([http://www.crncc.nihr.ac.uk/about\\_us/stroke\\_research\\_network/in\\_your\\_area/west\\_midlands](http://www.crncc.nihr.ac.uk/about_us/stroke_research_network/in_your_area/west_midlands)). The participatory workshop examined the pros and cons of cueing the gait or arm movements of Stroke, Parkinson's, Head injury, Ataxic, and other patients using the Haptic Bracelets as compared with other approaches. All participants were able to try out the Haptic Bracelets. Situations were identified where the Haptic Bracelets are not suitable for therapy (e.g. rehabilitation of grasp and reach, and in some Parkinson's cases where spasticity might be increased). Again, in order to inform design refinements, as well as collecting detailed comments, survey feedback from participants was evaluated to gain an impression of practitioners' initial views on the likely relative value of the three approaches.

**Table 2. General views of Physiotherapists at participative workshop**

Proposition	Agree (or Agree Strongly)	Agree Strongly
The tactile metronome has the potential to influence practice	91%	50%
Live monitoring and feedback on gait symmetry has the potential to influence practice	91%	50%
Flexible tactile cueing has the potential to influence practice	49%	33%

Comments from attendees included:

*"Maybe not appropriate for musculoskeletal patients with gait re-training in higher levels such as sporting injuries."*

*"May help with children and developmental problems, for tapping etc."*

*"Consider how therapists use, sensory input to facilitate neurological rehabilitation & the effects sensory stimulation can have on aspects such as tone/spasticity/muscle activation".*

### 3.3 Pilot Study with stroke survivor

For a preliminary pilot study, in order to investigate the effects of tactile cueing with the Haptic Bracelets in gait rehabilitation, we recruited a female participant with right hemiparesis aged 69 years, who provided written informed consent. Favourable ethical opinion was granted by the local Research Ethics Committee. Testing took place in the Motion & Performance Centre at the University of Worcester. Full-body marker trajectory data was collected at 60Hz using a 15 camera Vicon system, using standard clinical gait analysis procedures. We had envisaged our volunteer wearing a bracelet on each ankle, but on the day of the study she expressed a preference for wearing a single bracelet on her left (non-paretic) wrist. From a design point of view, this constitutes valuable user feedback (and the slight change remained within the existing ethical opinion) so we readily concurred. During pre-test, our participant performed 5 standard gait trials for baseline measures. This was followed by 5 walking trials with steps cued by the tactile device worn on her left wrist, followed by a final 5 un-cued walking trials. Analysis of the motion capture data (table 3) showed that the participant's paretic step length, hip range of motion (ROM), peak knee flexion during swing, and ankle range of motion increased above the minimum detectable change

threshold when cued with the tactile device compared to her baseline values [28,29]. This suggests that the immediate improvements observed though tactile cueing were clinically meaningful. The participant reported that she felt the tactile bracelet helped to generate an even walking pace, and that she felt she was using her hip more to swing her leg through straighter.



Figure 3. Preparing for the pilot study

Comments by the participant included

*"I must say its makes you stand up straighter"*

*"When I stand up straight my hips move better and I walk more smoothly and it's easier."*

*"I think it might help to remind you that you should be walking in this way"*

*"It does help .... this helps me to walk in time. It's just sort of having an even pace ... which helps me stand up straight and walk properly."*

**Table 3. Key values from motion capture data**

	Baseline	Haptic	Post
Speed ( $\text{m.s}^{-1}$ )	0.82	0.85	0.81
Non-paretic step time (s)	0.52	0.54	0.52
Paretic step time (s)	0.63	0.63	0.63
Non-paretic step length (m)	0.47	0.48	0.47
Paretic step length (m)	0.46	0.49	0.45
Paretic hip ROM (degrees ( $^{\circ}$ ))	31.8	35	33.3
Paretic knee peak flex swing ( $^{\circ}$ )	32.3	39.8	37.8
Paretic ankle ROM ( $^{\circ}$ )	24.5	27.6	25.1

## 4. CONCLUSIONS

Recovery of walking function is a vital goal of rehabilitation after stroke. Existing therapies using audio metronomes have been reported to have valuable immediate effects, but gait asymmetry can be very resistant to long term change. Audio cueing can be unsuitable outside the lab, due to dangers associated with earphone use near to motor vehicles, bicycles or even other pedestrians. Tactile cueing has potential to offer similar benefits to an auditory cue. In portable form, this approach could be used outside the lab for long periods without the problems associated with audio cueing. We have outlined three potential applications of the Haptic Bracelets in gait rehabilitation post-stroke, and have reported on an initial pilot study with an individual post-hemiparetic stroke. The preliminary data suggests that a tactile device may have immediate benefits for walking in individuals post-stroke and warrants further investigation.

## 5. ACKNOWLEDGMENTS

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